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RESEARCH ARTICLE

Regulation of Rainwater in Quyuan Park Using the SWMM: A Case of Changde City, China

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ABSTRACT

This study focuses on Quyuan Park in Changde City, Hunan Province, China, and compares two development scenarios: one without a sponge facility and one with a combined sponge facility. The SWMM model was used to simulate total runoff, peak flow, and peak time under 2-hour rainfall events with recurrence periods of 1 year, 3 years, 5 years, and 10 years. The results demonstrate that the SWMM model can accurately quantify the runoff reduction performance of various sponge facilities, providing a reliable theoretical foundation and data support for addressing urban stormwater management challenges. The findings highlight the significant advantages of sponge facilities in reducing runoff and delaying flood peaks, particularly in controlling peak flow and extending the peak occurrence time. This study offers valuable data and insights for advancing the application of sponge city strategies to mitigate urban flooding.

Contribution/Originality: The paper's primary contribution is finding that sponge city techniques, incorporating Low Impact Development (LID) features, significantly reduce and delay peak stormwater flows, mitigating urban flood risks in Quyuan Park. This study provides critical insights into urban park design for sustainable stormwater management under varying recurrence periods, enhancing urban flood resilience.

1. Introduction

In 1971, the U.S. Environmental Protection Agency (EPA) introduced the Storm Water Management Model (SWMM) as an advanced tool to simulate and manage urban stormwater systems, addressing a critical need for effective flood control and water quality management in urban environments (Zhu & Chen, 2017). SWMM is a dynamic rainfall-runoff simulation model capable of analyzing both single-event and long-term (continuous) rainfall events in urban areas. Over the past five decades, the SWMM model has evolved significantly, undergoing numerous updates and enhancements. The latest version, SWMM 5.1, has incorporated an upgraded module for Low Impact Development

(LID) facilities, which is of particular importance in modern urban planning, especially in the context of sustainable development and sponge city initiatives (Li et al., 2016).

The introduction of the Low Impact Development Module (LIDM) in SWMM 5.1 represents a key advancement, enabling the model to simulate and evaluate the hydrological effects of LID facilities designed to mitigate the impact of urbanization on stormwater systems by promoting natural water infiltration and reducing runoff. The LIDM module can simulate crucial parameters, including rainfall-runoff relationships, peak flow, and water quality across different rainfall intensities and recurrence intervals (Luan et al., 2019; Zoppou, 2001). This provides essential data for urban planners to optimize the layout, capacity, and efficiency of LID facilities in urban environments. In particular, the use of LID facilities has become a cornerstone of sponge city development, which seeks to enhance urban resilience to flooding and improve water management through nature-based solutions.

While significant research has been conducted on the use of SWMM and LID facilities in various urban settings, most existing studies in China have focused on residential areas, roadways, and other municipal infrastructures (Liu et al., 2014). These studies emphasize the importance of runoff control and flood mitigation in densely built environments, but they often overlook the potential contribution of urban parks, which can serve as large, permeable spaces within cities. Urban parks, with their extensive vegetation and natural landscapes, play a vital role in rainwater absorption, soil infiltration, and improving the overall urban hydrological cycle (Konijnendijk et al., 2013; Qiu & Turner, 2013). As key components of urban green infrastructure, parks not only contribute to biodiversity and recreational opportunities but also significantly reduce surface runoff, lower flood risks, and improve water quality by filtering pollutants. However, much of the research on urban parks has been qualitative, focusing on their general ecological and aesthetic benefits without incorporating quantitative models to assess their impact on stormwater management (Fletcher et al., 2013).

Given the increasing frequency and intensity of extreme weather events due to climate change, a more detailed understanding of the role urban parks can play in stormwater management is urgently needed. The use of quantitative methods, such as the SWMM model, can help provide more precise evaluations of how parks contribute to urban flood control, water retention, and runoff reduction. This is especially relevant for sponge city initiatives, where parks can be designed or retrofitted to enhance their stormwater management capabilities (Ji & Rao, 2023).

This study focuses on Quyuan Park in Changde City, Hunan Province, China, a typical urban park that has been integrated into the city’s sponge city development efforts. By applying the SWMM model, this study conducts a quantitative analysis of rainfall-runoff, peak flow, and the overall effectiveness of the park under different rainfall scenarios. The aim is to assess Quyuan Park's role within the larger urban stormwater management system and to provide data-driven support for the planning and optimization of sponge city infrastructure. The findings of this study are expected to contribute valuable insights into how urban parks can be better utilized in stormwater management and how sponge city strategies can be further refined to increase urban resilience against flooding.

2. Materials and methods

2.1. General description of the research area

Quyuan Park, located in the heart of Changde City, Hunan Province, within Wuling District, serves as a critical urban green space and stormwater management area. The region is characterized by a subtropical monsoon climate, with distinct seasonal variations in temperature and rainfall. Summers are typically hot and humid, with temperatures often exceeding 35°C, while winters are mild and relatively short. The climate is strongly influenced by the East Asian monsoon, leading to significant seasonal rainfall patterns. Most precipitation occurs during the summer months, with June, July, and August alone contributing nearly 70% of the annual rainfall. These summer months are prone to frequent heavy rainstorms, often bringing intense rainfall within short periods. The average annual precipitation in Changde is approximately 1,400 mm, although it can vary dramatically. In particularly wet years, precipitation can reach up to 1,800 mm, while drier years may see as little as 1,000 mm (Changde City Natural resources and planning Bureau, 2024). This uneven distribution of rainfall, coupled with the intensity of summer storms, makes the region highly vulnerable to urban flooding, especially during extreme weather events.

Quyuan Park spans 27.8 hectares and was chosen for this research due to its significant role in managing urban stormwater and mitigating flood risks. Quyuan Park is geographically positioned with the Yuan River to its south, residential areas to its north and east, and Ziling Road to its west (Figure 1). The park is not only a recreational and ecological asset but also a functional part of the city's stormwater management strategy, especially under the Sponge City framework. A central feature of the park is its lake, which serves as a critical component in retaining and managing rainwater. This lake, alongside other facilities, plays a crucial role in controlling stormwater during heavy rainfall events, reducing the risk of flooding in the surrounding areas.

Figure 1: Quyuan Park area and its surroundings

Source: Self-drawn by the author

The park incorporates various sponge city facilities such as rain gardens, infiltration trenches, sunken green spaces, and rain barrels. These facilities are designed to capture and store rainwater within the park itself, rather than directing it into the municipal drainage system. Rainwater is absorbed and filtered through these natural systems, allowing for gradual infiltration into the ground or storage in the park's lake. For instance, rain gardens utilize carefully selected vegetation and soil layers to absorb rainwater, reducing surface runoff and improving water quality before the water either infiltrates or flows into the lake. Infiltration trenches help channel rainwater into the ground, further promoting natural infiltration. Sunken green spaces are designed to collect water, allowing it to slowly percolate into the soil. Rain barrels, meanwhile, store rainwater for later use, particularly for landscape irrigation.

Together, these sponge facilities help to alleviate pressure on traditional drainage systems and prevent urban flooding by retaining rainwater within the park. The lake acts as a reservoir, temporarily storing excess rainwater and allowing for controlled release or infiltration, ensuring that the park can effectively manage large volumes of water during storm events. This combination of natural and engineered systems within the park is a vital part of the city's broader flood control strategy, enhancing resilience to extreme rainfall and contributing to urban stormwater management.

Quyuan Park plays a pivotal role in the city's stormwater management system by integrating various sponge facilities that help capture, retain, and manage rainwater. The park's lake serves as a central storage feature, enabling effective flood control and water management. This study aims to assess the effectiveness of these facilities, using the SWMM model to conduct a quantitative analysis of rainfall runoff and peak flow under different rainfall conditions. The findings will provide valuable insights into how sponge city infrastructure can be further optimized to improve urban resilience and flood control.

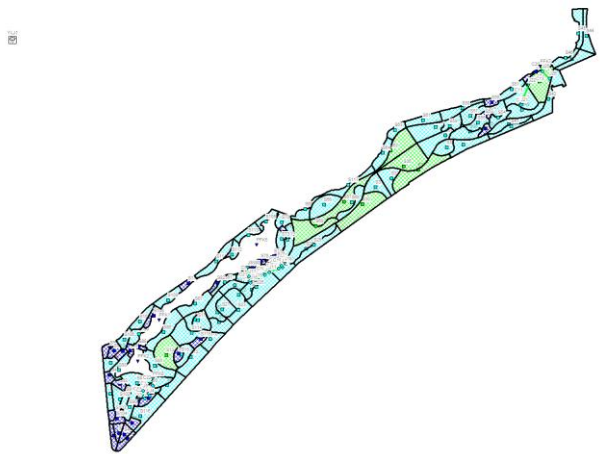
Based on the topographical features, surface characteristics, and runoff flow patterns of Quyuan Park, the research area has been systematically divided into 117 distinct sub-catchment areas. This division was carried out through a structured process. First, primary catchment areas were delineated according to the site's natural terrain, slopes, and man-made features such as roads and pathways, which influence runoff flow. These primary divisions provided a broad framework for understanding how stormwater flows across different parts of the park.

To further refine this division, the Thiessen Polygon method was applied, allowing for a more detailed subdivision of the primary catchments into secondary catchment areas. This method, commonly used in hydrological analysis, helps define localized drainage zones around specific points, such as stormwater inlets. Through this approach, the boundaries of the sub-catchment areas were fine-tuned to ensure that each area's runoff was directed to the nearest stormwater management feature. Ultimately, this combination of topographical analysis and the Thiessen Polygon method resulted in the creation of 117 distinct sub-catchment areas. Each sub-catchment represents a localized drainage zone, facilitating detailed analysis of rainfall and stormwater flows across the site. These divisions are crucial for understanding the distribution of stormwater within the park, as well as how different areas contribute to overall runoff and water retention. This detailed catchment mapping allows for more precise stormwater management and highlights the park's capacity for runoff control and flood mitigation.

To effectively manage and control stormwater, six strategically placed discharge outlets have been established throughout the park. These outlets are designed to guide excess water toward specific collection points, such as the central lake, ensuring that stormwater is appropriately managed within the park itself. The park's drainage system also includes a network of 24 drainage pipe segments, essential for transporting water away from key areas and directing it to the park's stormwater retention facilities. These pipes work in conjunction with both natural and engineered sponge city features to ensure balanced and efficient stormwater flow. In addition to the discharge outlets and drainage pipes, the park is equipped with 26 stormwater inlets that serve as entry points where surface runoff is collected and directed into the drainage system. These inlets are positioned based on the topographical layout and runoff flow direction, ensuring optimal capture and management of stormwater across the park.

The overall layout and division of the park's sub-catchment areas, along with the placement of discharge outlets, drainage pipes, and stormwater inlets, are illustrated in Figure 2. This detailed representation of the park's hydrological structure is essential for understanding its stormwater management system and the effectiveness of its sponge city facilities in regulating rainfall runoff and mitigating flood risks.

Figure 2: Sub-catchment area map.



Source: Self-drawn by the author

2.2. Modeling of the research area

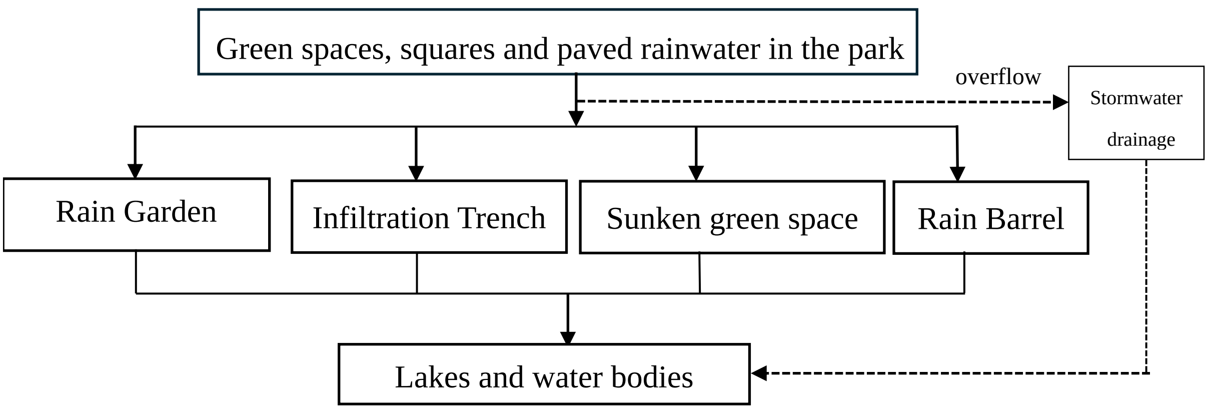
In alignment with the principles of stormwater management, which focus on source reduction, midway transmission, and end-point regulation and storage, the sponge city measures implemented in Quyuan Park are meticulously designed to match the park's unique topography, hydrology, and ecological characteristics (Burns et al., 2012; Fletcher et al., 2015). These interventions are critical to enhancing stormwater management within the park and balancing flood mitigation and ecological sustainability (Dietz, 2007; Xiang et al., 2019). Key sponge city measures employed include rain gardens, infiltration trenches, sunken green spaces, and rain barrels, each contributing to stormwater collection, retention, and infiltration (Roy et al., 2008).

Placing strategically in low-lying areas, rain gardens serve as bio-retention zones that collect surface runoff during rainfall events. These vegetated areas are planted with species that absorb water, slow runoff, and filter pollutants, which not only reduces the volume of stormwater but also improves its quality (Dietz, 2007). Infiltration trenches, meanwhile, capture runoff and promote its percolation into the underlying soil, supporting groundwater recharge while alleviating the burden on surface drainage infrastructure (Fletcher et al., 2013). Larger sunken green spaces provide temporary storage for excess water during heavy storms, reducing localized flooding and further facilitating infiltration (Li et al., 2017). Green infrastructure, often called nature-based solutions, enhances the quality of urban living (McFarland et al., 2019).

Collectively, these facilities significantly reduce stormwater runoff and peak flow rates, while also offering long-term ecological benefits such as improved groundwater recharge, enhanced biodiversity, and strengthened ecosystem resilience (Gill et al., 2007). By distributing these facilities throughout the park, a robust and integrated stormwater management system is established, allowing for the effective regulation of stormwater during periods of heavy rainfall (Li et al., 2017).

The strategic design of these facilities ensures that stormwater is efficiently managed from its initial collection at the source to its eventual infiltration or storage. The layout and connectivity of the park's drainage system, as depicted in Figure 3, illustrate how the various components of the sponge city design work together to regulate runoff and reduce flood risks. This integration ultimately supports the sustainability and resilience of the urban stormwater system within Quyuan Park.

Figure 3: Stormwater drainage path of sponge facility.



Source: Self-drawn by the author

2.3. Module Parameter Settings

The module parameters in this study were determined based on the specific soil characteristics, precipitation patterns, and hydrological modeling principles for Quyuan Park and its surrounding areas. A key part of the modeling is the application of the Horton (1940) infiltration model, which accurately represents the process of rainfall infiltration. This model was chosen because it can simulate the changing infiltration rate over time, which is critical for analyzing rainwater dynamics in areas with variable soil permeability. In this case, the maximum infiltration rate was set at 76.2 mm/h, and the minimum infiltration rate was set at 2.16 mm/h, reflecting the permeability of the local soil. The higher initial infiltration rate represents the initial absorption of rainwater, while the lower infiltration rate represents the soil's ability to continue absorbing water after saturation (Horton, 1940).

For surface runoff modeling, the non-linear reservoir method was adopted, which considers the non-linear relationship between surface water flow and storage, providing a more accurate representation of the runoff process (Beven & Kirkby, 1979). This method can realistically simulate how rainwater is temporarily stored on the surface and gradually released, reflecting the complexity of hydrological dynamics during storm events. In addition, to model the complex dynamics of water flow through the park's drainage system, the dynamic wave equation was used to simulate pipe flow. This method is crucial for capturing unsteady flow conditions and backwater effects during heavy rainfall events, allowing a detailed analysis of rainwater flow within the underground drainage pipes.

Another important parameter is the depression storage on impervious surfaces, which was set at 1.27 mm. Depression storage refers to small depressions on impervious surfaces that can temporarily hold rainwater before it enters the drainage system. This value reflects the ability of impervious areas such as roads and plazas within the park to store and slow down rainwater, thereby reducing peak runoff and delaying the onset of surface runoff.

In terms of rainfall simulation, the study focused on rainfall events with recurrence intervals of 1 year, 3 years, 5 years, and 10 years, each lasting for 2 hours. These recurrence intervals were selected to assess the performance of the park's drainage system under varying storm intensities (from frequent to severe storm events). To ensure the realism of the rainfall simulation, the Chicago storm method was used. This method is known for representing the temporal distribution of rainfall during storm events and is particularly suitable for urban hydrology studies (Keifer & Chu, 1957). The storm intensity formula for Changde City was combined with the Chicago storm method to ensure that the simulated rainfall events closely match the actual climatic conditions of the city.

To evaluate the performance of the park's sponge city facilities, the study considered two scenarios: one with Low Impact Development (LID) measures and one without these sponge city facilities. The LID scenario included measures such as rain gardens, infiltration trenches, sunken green spaces, and rain barrels, which aim to reduce surface runoff, enhance infiltration, and promote rainwater retention (Ahiablame et al., 2012). By comparing the results of these two scenarios, the study was able to assess the effectiveness of sponge city interventions in controlling stormwater runoff, reducing peak flow, and mitigating flood risks.

3. Results and discussion

The selection of parameters for the Low Impact Development (LID) Controls module in this study was primarily based on the site-specific characteristics and design specifications of Quyuan Park. The park incorporates several key sponge city techniques aimed at enhancing stormwater management and promoting infiltration, such as Rain Gardens, Infiltration Trenches, Sunken Green Spaces, and Rain Barrels. These facilities were integrated into the model to assess their performance under various rainfall scenarios, allowing for a detailed analysis of their effectiveness in reducing runoff and controlling peak flow rates.

Evaporation data, a critical factor influencing water balance in LID systems, was derived from the “2022 Changde City Water Resources Bulletin.” Based on local meteorological conditions, the daily evaporation rate was adjusted to an average of 4.2 mm/day. This value was incorporated into the model to simulate water loss due to evaporation from the surface of rain gardens, bio-retention cells, and other permeable spaces. Accurately representing evaporation is essential, as it directly impacts the available storage capacity within LID facilities and influences their long-term effectiveness in mitigating runoff.

The sponge facilities used in Quyuan Park were selected to target different aspects of urban stormwater management. Rain Gardens and Bio-Retention Cells are designed to capture runoff from nearby impervious surfaces, such as walkways and parking lots. These systems utilize vegetation and engineered soils to promote infiltration, enhance evapotranspiration, and filter pollutants from stormwater. Infiltration Trenches are narrow, gravel-filled channels that allow stormwater to infiltrate directly into the underlying soil, providing both storage and filtration. Rain Barrels are designed to capture and store rainwater from rooftops for future non-potable uses, such as irrigation, which can help reduce demand on municipal water supplies during dry periods. Sunken Green Spaces, similar to bio-retention cells, provide a large storage capacity and can temporarily hold and gradually release stormwater during heavy rain events, mitigating the impact on the park's drainage system.

Table 1 outlines the key simulation parameters for these LID facilities, including factors such as surface slope, porosity, and storage thickness. These parameters were selected based on each facility's specific design, ensuring that the model accurately reflects the performance of Quyuan Park's stormwater management infrastructure.

Table 1: LID facility parameters.

Layers	**Parameters**	**Units**	**Bio-Retention Cell**	**Rain Garden**	**Infiltration Trench**	**Rain Barrel**
Surface	Berm Height	mm	250	200	200	2000
	Vegetation Volume Fraction		0.8	0.8	0.8	0.0
	Surface Roughness	%	0.1	0.1	0.1	--
	Surface Slope	%	1.0	1.0	1	--
Soil	Thickness	mm	300	300	3	--
	Porosity		0.3	0.5	--	--
	Field Capacity		0.2	0.2	--	--
	Wilting Point		0.1	0.1	--	--
	Conductivity	Mm/h	500	500	--	--
	Conductivity slope		10.0	10.0	--	--
	Suction Head	mm	500	500	--	--
Storage	Thickness	mm	550	--	600	--
	Void Ratio		0.75	--	0.75	--
	Seepage Rate		500	--	500	--
	Clogging Factor		0	--	--	--
Underdrain	Flow Coefficient		0.5	--	0.5	0
	Flow Exponent		0.5	--	0.5	0.5
	Offset Height	mm	50	--	50	6

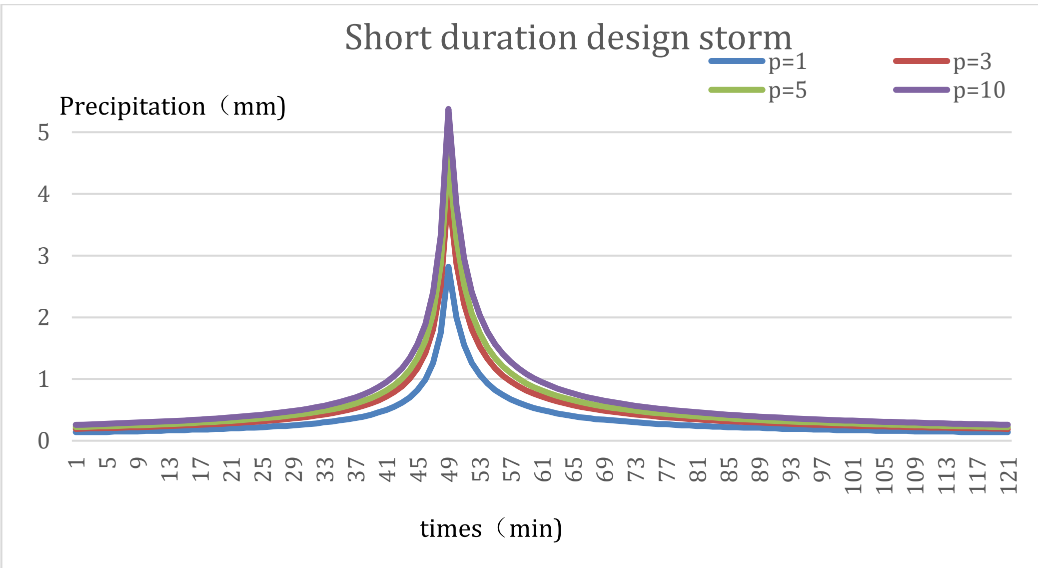
The design storm scenarios for the model were chosen to reflect different levels of rainfall intensity, ranging from more frequent, moderate storms to rare, extreme events. The design storms include recurrence intervals of 1, 3, 5, and 10 years, with each storm lasting for 2 hours. These storm events were selected to evaluate the LID facilities' performance under varying levels of stress, from minor events to significant storms that can cause urban flooding.

The Chicago Storm Method was used to simulate the temporal distribution of rainfall during these events. This method is widely employed in urban hydrology because it accurately represents the uneven distribution of rainfall intensity throughout a storm event. Table 2 and Figure 4 provide a summary of the average and peak rainfall intensities for the different design storms. These values were calculated based on local precipitation records and adapted to the model to ensure that the storm simulations align with the typical weather conditions in Changde City.

Table 2: Summary of short-duration design storms

Recurrence period /a	**2h precipitation (mm)**	**Average rainfall intensity (mm/min)**	**Peak rainfall intensity (mm/min)**
p=1	43.76	0.36	2.82
p=3	62.64	0.52	4.04
p=5	71.44	0.60	4.61
p=10	83.38	0.69	5.38

Figure 4: Short duration design storm.



The simulation results indicate that the LID facilities implemented in Quyuan Park perform effectively in managing stormwater during all modeled storm events. Rain Gardens and Bio-Retention Cells significantly reduced surface runoff, particularly during smaller storm events, by promoting infiltration and evapotranspiration. Infiltration Trenches and Sunken Green Spaces played a crucial role in delaying peak flows and reducing the overall volume of runoff, helping to mitigate the impacts of urban flooding. Rain Barrels, though limited in storage capacity, contributed to stormwater retention and can help offset water demand for non-potable uses.

The results, summarized in Table 3, reveal substantial differences in stormwater runoff behavior between the two scenarios. Without sponge facilities, the peak flow rates are significantly higher across all recurrence periods. In particular, for extreme storm events (P=5 and P=10), the peak flows exceed 12,000 L/s and 14,000 L/s, respectively. This sharp increase in peak flow rates suggests that the existing drainage infrastructure alone may struggle to manage intense rainfall events, increasing the risk of localized flooding within the park.

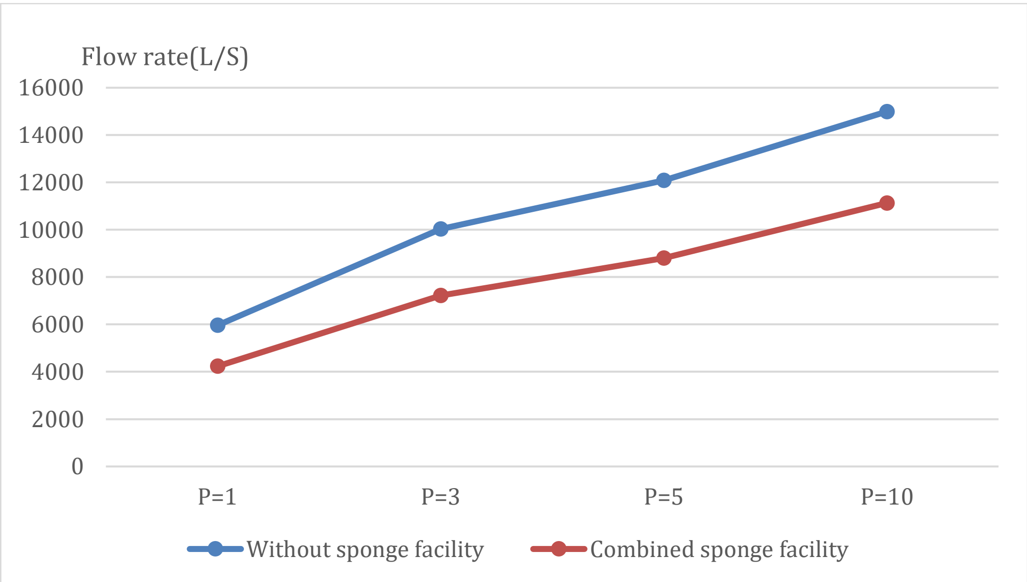
In contrast, the scenario with the implementation of a combined sponge facility (including Rain Gardens, Infiltration Trenches, Sunken Green Spaces, and Rain Barrels) demonstrates a significant reduction in peak flows. As shown in Table 3, the peak flow rates for the same recurrence periods are consistently lower when sponge facilities are incorporated into the model. For example, the peak flow rate during a 10-year storm event decreases from 14,993.96 L/s to 11,131.19 L/s, representing a reduction of approximately 26%. Similarly, for a 1-year storm event, the peak flow is reduced by nearly 29% with the addition of sponge city features.

Table 3: Peak flows for different recurrence periods for each modelled formation at low recurrence periods (L/S)

Modelling scenario	P=1	P=3	P=5	P=10
Without sponge facility	5961.56	10028.05	12080.67	14993.96
Combined sponge facility	4231.45	7215.35	8805.86	11131.19

Figure 5 presents the peak flow values for each modeled recurrence period, providing a clear visual comparison between the two scenarios. It shows that with the combined sponge facility, the peak flow curves are smoother and less steep. This indicates that sponge city techniques effectively attenuate and store stormwater, reducing the peak discharge rate and extending the time required to reach the peak.

Figure 5. p=1\3\5\10aPeak flows for each modeled formation in the recurrence period



3.1. Flow Process Analysis at Different Recurrence Periods

Figure 6, Figure 7, Figure 8, and Figure 9 illustrate the line graphs of flow processes for the recurrence periods P=1, P=3, P=5, and P=10, respectively. In these figures, the flow curves for the scenario without sponge facilities exhibit a sharp and rapid rise to the peak, followed by an equally steep decline. This flow pattern suggests that in the absence of stormwater management interventions, the park's drainage system is subjected to a sudden surge in runoff, increasing the risk of flash flooding. Conversely, in the scenario with sponge facilities, the flow processes show a much more gradual rise, with the peak flow occurring later and at a significantly lower magnitude. This delay in the time to peak flow is particularly beneficial, as it allows the park's drainage system to manage stormwater more efficiently, preventing overloading and reducing the likelihood of flooding. For example, Figure 6 shows that during a 1-year storm event, the sponge facility delays the peak flow by approximately 20 minutes compared to the scenario without sponge infrastructure.

As the recurrence periods increase, the effectiveness of the sponge facilities in reducing runoff diminishes slightly. Figure 9 shows that for a 10-year storm event, while the sponge facility still significantly reduces the peak flow, the time to reach the flood peak is shorter than in lower recurrence periods, indicating that the system's ability to retain stormwater becomes more strained under extreme rainfall conditions. Despite this, the sponge facility continues to offer substantial benefits, mitigating the flood risk by reducing both the volume and rate of runoff.

Figure 6: Line graphs of flow processes without and with sponge facilities at P=1

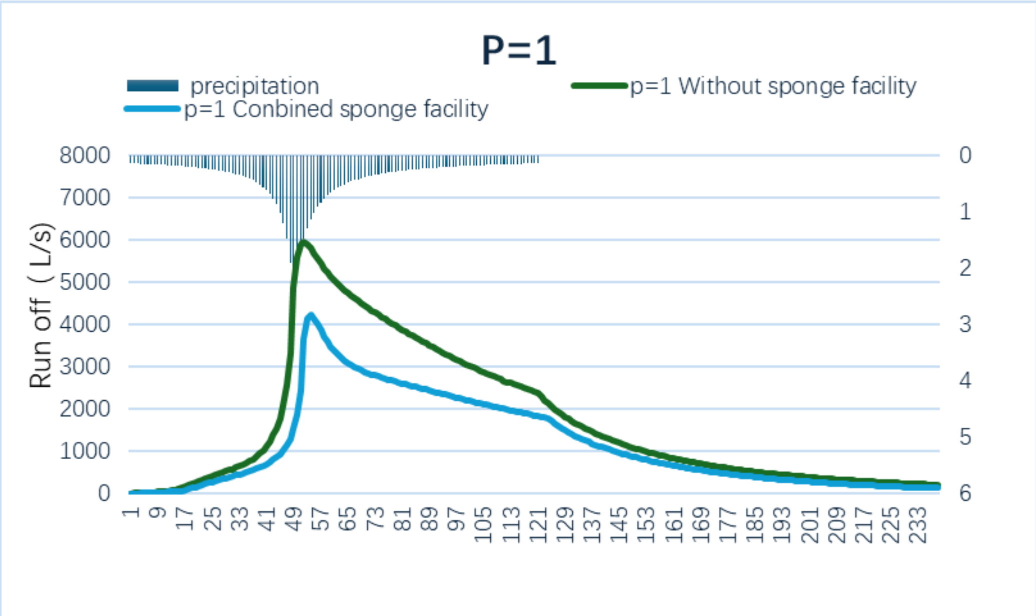


Figure 7. Line graphs of flow processes without and with sponge facilities at P=3

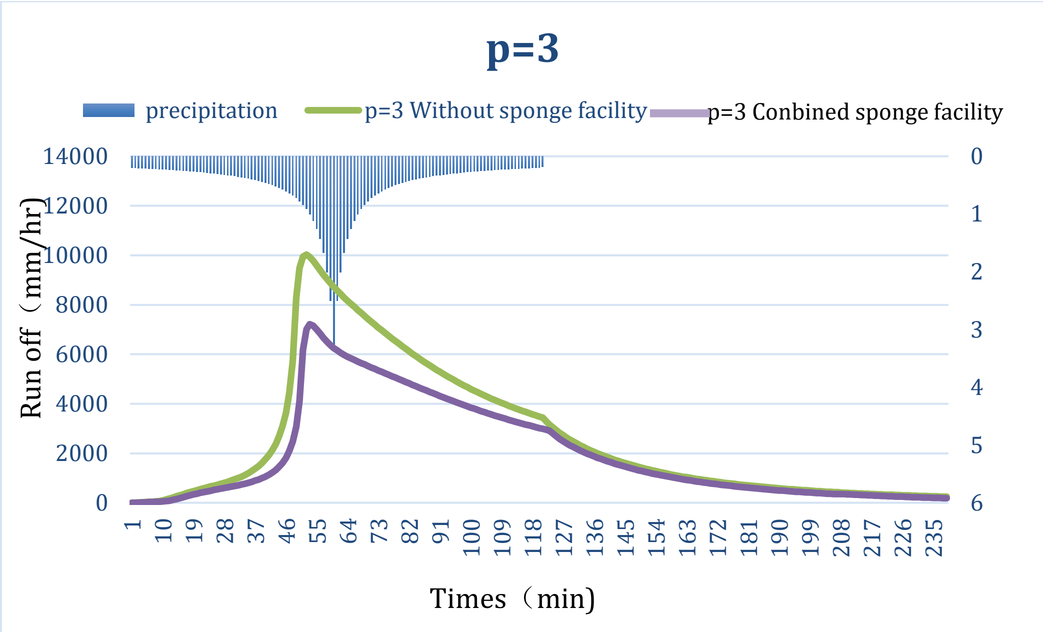


Figure 8. Line graphs of flow processes without and with sponge facilities at P=5

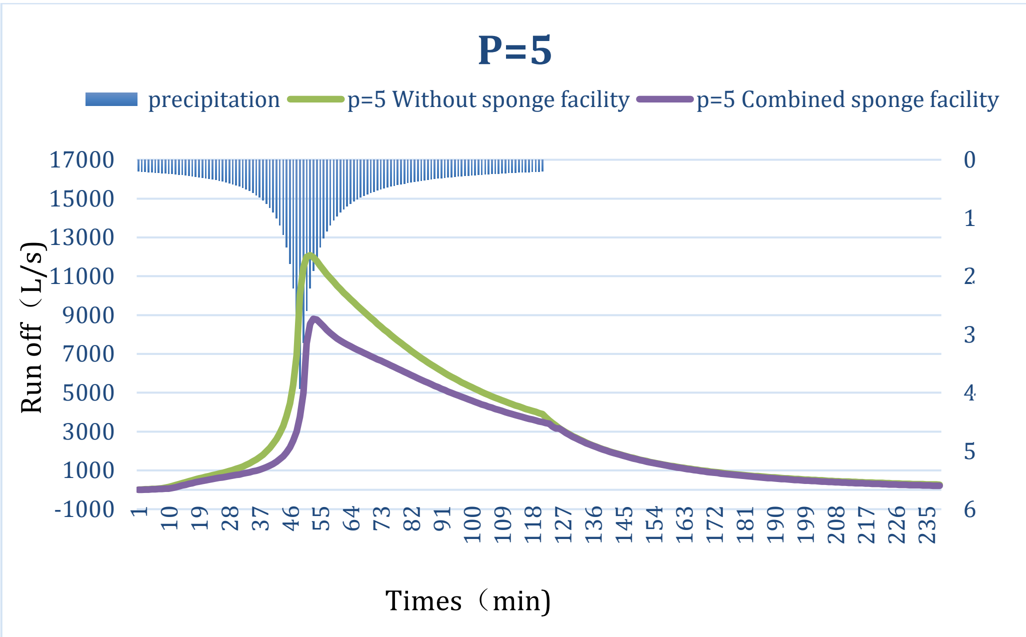
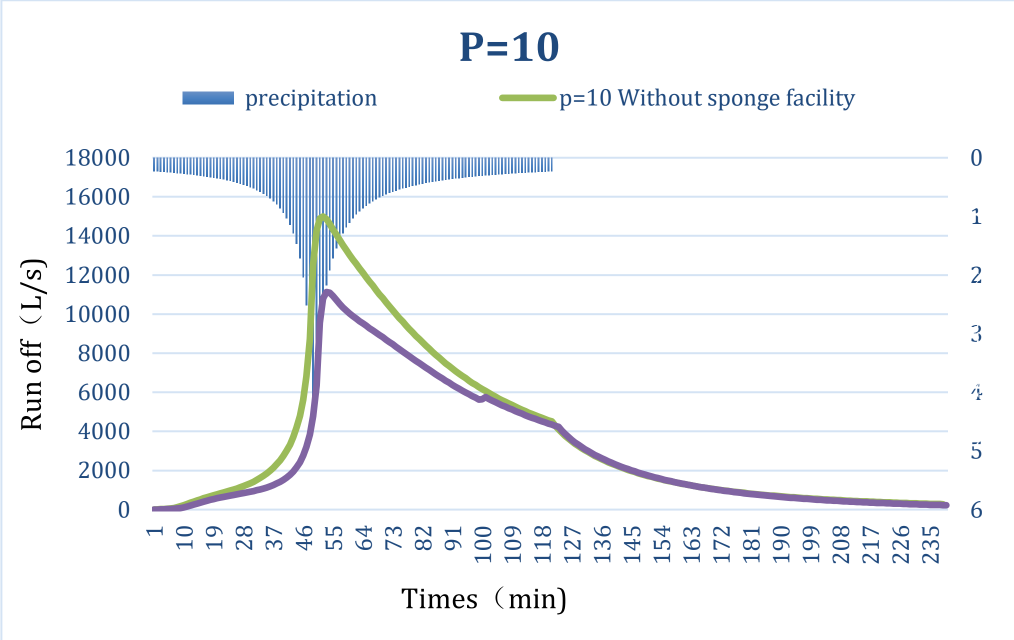


Figure 9. Line graphs of flow processes without and with sponge facilities at P=10



3.2. Sponge Facility Performance Across Recurrence Periods

By comparing Figure 6, Figure 7, Figure 8, and Figure 9, it becomes evident that the runoff reduction efficiency of the sponge facility decreases as the recurrence period and rainfall intensity increase. However, the overall effectiveness of the sponge city techniques remains notable, particularly for moderate storm events. For the 1-year recurrence period (P=1), the combined sponge facility reduces the peak flow by approximately 29%, whereas for the 10-year period (P=10), the reduction is still substantial at around 26%. The integration of multiple LID (low-impact development) features, such as bio-retention cells, rain gardens, and sunken green spaces, plays a pivotal role in this reduction. These facilities not only enhance infiltration and evapotranspiration but also provide temporary storage for stormwater, allowing it to be released gradually over time. This results in a smoother and extended flow curve, as evidenced by the differences between the two scenarios.

3.3. Impact of Sponge Facilities on Urban Flooding

The construction of sponge facilities in Quyuan Park has demonstrated its effectiveness in mitigating urban flooding, particularly during intense storm events. The analysis shows that the sponge facilities significantly reduce peak runoff, alleviate pressure on the park’s drainage system, and improve overall flood resilience. The use of LID techniques such as infiltration trenches and rain gardens contribute to increased stormwater retention and infiltration, reducing the volume of surface runoff that enters the drainage system. This is especially important in urban environments like Changde, where impervious surfaces are prevalent, and stormwater management infrastructure is often overburdened during heavy rainfall.

Moreover, the sponge facility's ability to delay peak flow provides additional time for stormwater to be managed, further decreasing the risk of flash flooding. This time delay is particularly beneficial for the park and surrounding urban areas, as it allows for more controlled drainage and reduces the likelihood of system overload during extreme rainfall events.

4. Conclusion

This study investigated the impact of sponge city techniques on stormwater management in Quyuan Park, focusing on their effectiveness in reducing runoff, managing peak flows, and improving urban flood resilience. The research was conducted by analyzing flow curves under different recurrence periods (1, 3, 5, and 10 years) for two scenarios: one without sponge facilities and one with a combination of various Low Impact Development (LID) features such as rain gardens, infiltration trenches, and sunken green spaces. The findings demonstrated that sponge city infrastructure significantly mitigates peak flow rates, with reductions ranging from 26% to 29% across all recurrence periods. In extreme storm events, the facilities not only lowered peak discharge but also delayed the time to peak flow, reducing the risk of sudden flooding and relieving pressure on the park's drainage system. The implementation of LID features also enhanced stormwater retention, infiltration, and evapotranspiration, contributing to more sustainable water management.

Despite a slight decrease in effectiveness during more intense rainfall events, sponge city techniques still provided substantial benefits in stormwater attenuation and flood risk reduction. This study underscores the importance of incorporating sponge city principles into urban planning and highlights the critical role that urban parks can play in stormwater management. The results offer valuable insights for designing resilient urban landscapes and adapting to the growing challenges of urban flooding.

Ethics Approval and Consent to Participate

The researchers used the research ethics provided by the Research Ethics Committee of Universiti Teknologi MARA. All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the institutional research committee. Informed consent was obtained from all participants according to the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of Interest.

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